Review of Heavy Metals Pollution in China in Agricultural and Urban Soils

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Introduction

Soil is the subsystem for biogeochemical cycles such as nutrient recycling, energy exchange, moderation of greenhouse gas fluxes and recycling of carbon.[1,2] Soil management is key to maintaining high quality food and fiber production for the world's growing population.[3] However, as agricultural inputs, urbanization and economic development continue, heavy metals are being deposited into soil.[4,5] The concentration of heavy metals in the soil, due to agricultural input, fast urbanization and industrialization is a problem affecting a large area of China.[5] As heavy metals are not degraded through chemical and physical weathering, their concentrations are increased through time, altering soil properties and minimizing the availability of nutrients for biological activities.[6]

Soil heavy metals pollution degrades soil's inherent capacity for ecological functions. These soil functions include buffering anthropogenic perturbations, sustaining productivity, moderating pollutants, protecting watersheds, improving water and air quality, and others.[2] There has been significant degradation of these soil functions

Background. The concentrations of heavy metals in soil and potential risks to the environment and public health are receiving increased attention in China.
Objectives. The objective of this paper is to review and analyze heavy metals soil contamination in urban and agricultural areas and on a national scale in China.
Methods. Initially, data on soil heavy metals concentration levels were gathered from previous studies and narratively analyzed. A further statistical analysis was performed using the geo-accumulation index (I_{geo}), Nemerow integrated pollution index (NIPI), mean, standard deviation (SD), skewness and kurtosis. Pollution levels were calculated and tabulated to illustrate overall spatial variations. In addition, pollution sources, remedial measures and impact of soil contamination as well as limitations are addressed.
Results. The concentration level of heavy metals was above the natural background level in most areas of China. The problem was more prevalent in urban soils than agricultural soils. At the national level, the soil in most of the southern provinces and Beijing were heavily polluted. Even though the pollution condition based on I_{geo} was promising, the Nemerow integrated pollution level was the most worrisome. The soils in about 53% of the provinces were moderately to heavily polluted (NIPI>2). The effects were noticed in terms of both public and ecological health risks. The major sources were waste gas, wastewater, and hazardous residuals from factories and agricultural inputs such as pesticides. Efforts have been made to reduce the concentrations and health risks of heavy metals, including policy interventions, controlling contamination sources, reducing the phytoavailability of heavy metals, selecting and rearing of grain cultivars with low risk of contamination, paddy water and fertilizer management, land use changes, phytoremediation and engineering techniques.
Conclusions. China is experiencing rapid economic and technological advancements. This increases the risk of heavy metals contamination of soil. If serious attention is not paid to this problem, soil toxicity and biological accumulation will continue to threaten the sustainability of China's development.
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around the world due to adverse changes in soil's physical, chemical and biological properties and soil protection is an international concern.[7] Accordingly, soil quality assessment is the main research emphasis of modern soil science for ensuring soil health and sustainability.[1] Careful consideration is necessary to monitor anthropogenic impacts on soil quality and to closely monitor long-term soil and environmental quality indicators.[8]

Following recognition of soil pollution as a serious problem in China, nationwide surveys of soil were conducted between 2005 and 2013.[9] These surveys covered more

than 70% of China's land area.[10] The survey reported that 16% of soil samples and 19% of agricultural soil was contaminated with heavy metals (exceeding the environmental quality standard). Of the soils considered to be polluted, 82.4% of contamination was due to metals and metalloids and the rest (17.6%) was due to organic contaminants.[10] Over 6 million hectares of farmland was polluted with industrial and urban wastes in the early 1990s, and soil affected by acid rain expanded from 1.5 to 2.5 million ha from 1985 to 1994. A relatively recent analysis also reported that about 10 million hectares of arable land in China was polluted by heavy metals.[11]

Even though levels of naturally occurring heavy metals are generally low in China, some studies have reported high levels of pollution of soil, air and water and negative affects on human health.[12] Protecting food security through soil management is one of the priorities of the central government.[13] However, the current soil quality monitoring system is insufficient to accurately determine soil contamination status.[13] Therefore, knowledge about the source, concentration, and pollution level of soil heavy metals is essential to soil remediation and protection.[14,15] This study aims to review the concentration, pollution level, sources and remediation of soil heavy metals in China.

Methods

First, publications addressing the specific review objectives across different spatial contexts were retrieved. Most of the reviewed papers were based on soil samples at a depth of 10 to 20 cm of topsoil. Sample sizes for the analyses of metals in agricultural soil (*Table 1*) were as follows: 6 (Beijing), 70 (Guangzhou), 76 (Yangzhou), 102 (Wuxi), 60

Abbreviations			
I_{geo}	Geo-accumulation index	*SD*	Standard deviation
NIPI	Nemerow integrated pollution index		

(Gansu), 30 (Chengdu), 100 (Taihang), 8 (Zhengzhou), 240 (Kunshan), 20 (Xuzhou), 14 (Jinghe), and 26 (Hainan).[16-27] The corresponding sample size for studies in urban soil (*Table 1*) were 773 (Beijing), 40 (Guangzhou), 273 (Shanghai), 319 (Qingdao), 30 (Jinchang), 82 (Hangzhou), 110 (Changsha), 48 (Hongkong), 215 (Luoyang), 138 (Nanjing), 39 (Changchun), 54 (Taicang), 286 (Fuyang), 20 (Shenyang), 21 (Xuzhou) and 132 (Fuzhou).[28-43] Soil sample size was generally higher among studies of urban soil than agricultural soil. This may be due to higher levels of metal pollution in urban soil that could not be represented by smaller samples.

The pollution index is a powerful tool for summarizing soil heavy metal contamination.[44] Various calculation methods were used such as pollution index (PI) and integrated pollution index, enrichment factor and geo-accumulation index (I_{geo}).[45] Further statistical analysis was performed based on the concentration levels of heavy metals in previous studies. These include the I_{geo}, Nemerow integrated pollution index (NIPI), mean, standard deviation (SD), skewness and kurtosis.

Nemerow integrated pollution index

First, the pollution index and average pollution index (PI_{avr}) were calculated.

$$Pollution\ index\ (PI) = \frac{CN}{BN}$$

Where Cn is the measured concentration value (mg/kg), and Bn is the soil background values of heavy metals (mg/kg).[46] It is a single pollution index. The average pollution index is calculated as follows:

$$PI_{avr} = \frac{1}{m} \sum_{i=1}^{m} PI$$

Where PI is the pollution index of heavy metal I and m is the number of heavy metals. After calculating PI and its average, a soil's overall pollution status was derived using the NIPI. This was used to quantify the total pollution status of soil by heavy metals.[47] It is derived as follows:

$$NIPI = \sqrt{\frac{PI^2_{avr} + PI^2_{Max}}{2}}$$

Where PI^2_{avr} is the average of the PI of all considered metals and PI^2_{max} is the maximum value. Soil pollution status was classified into five grades based on NIPI: NIPI ≤ 0.7 (safety domain), 0.7 < NIPI ≤1 (precaution domain), 1 < NIPI ≤ 2 (slight pollution), 2 < NIPI ≤ 3 (moderate pollution), and NIPI N ≥3 (heavy pollution).[48]

Geoaccumulation index

This method was designed in 1969 by Muller.[49] The formula is given as:

$$I_{geo} = log_2 \left(\frac{Cn}{1.5Bn} \right)$$

Where Cn is the measured concentration value (mg/kg), and Bn is the soil background value of heavy metals (mg/kg). It deals with the degree of a metals' input due to human activities with regard to environmental geochemistry background values.[50]

To minimize the effects of the variations of each metal's background values in the environment and influence of anthropogenic activities, Muller used the constant 1.5.[44] He also classified the geo-accumulation index into seven pollution grades: I_{geo} ≤0 (not polluted), 0<I_{geo} ≤1 (slightly to moderately polluted), 1<I_{geo} ≤2 (moderately polluted), 2< I_{geo} ≤3 (moderately to strongly polluted), 3 <I_{geo} ≤4 (strongly polluted), 4<I_{geo} ≤5 (strongly to extremely polluted) and I_{geo}>5 (extremely polluted).[51]

Soil heavy metals concentrations in China

Agricultural soil
Heavy metals concentrations have been rapidly increasing in China. The concentrations of heavy metals were below background values in only a few instances, and all mean concentration values were higher than their reference values (*Table 1*). The greatest variation was observed for zinc (Zn). Non-ferrous metal mining and smelting activities are a major source of Zn and show a high pollution rate (49.04%) in China.[52] Uneven distribution of mining sites and high Zn production may be responsible for this high spatial variation and elevation over background levels. These results and the variability of other metals are indicators of human influence. High variability indicates greater anthropogenic effects which alter the concentration of heavy metals.[53] Mercury (Hg) showed the least variability with a SD=0.21, which is very close to the mean (0.24). In addition, cadmium (Cd) showed the highest asymmetric distribution across sites (skewness=3.24 and kurtosis=10.64).

In response to the decline of farmland and the growing demand for food in China, agricultural intensification with modern inputs has increased. Irrigation, and use of chemical fertilizers and insecticides have accelerated the metals concentration of agricultural soils in China.[52] Chemical fertilizers and insecticides contribute to the high pollution rate for Cd (7.24%) and nickel (Ni) (3.04%), as well as 2% pollution of soil samples by copper (Cu) and Hg. Furthermore, waste discharged from 1.6 million enterprises in townships and others that have recently migrated to rural areas for cheaper land and low labor costs are other major sources of soil contamination. According to a report of the Environmental Monitoring Department in 2009, these enterprises discharged 5.9 billion tons of waste water and 13.2 million tons of particulate emissions in rural areas of China.[54]

Urban soil
As seen in Table 1, the concentration levels of heavy metals in urban soil were generally higher than in agricultural soil. This is a clear manifestation of the degree to which anthropogenic factors are contributing to spatial variability of heavy metal concentrations. With the exception of Cr and Ni in some urban areas and Pb in Taicang, the concentrations of all other heavy metals were higher than their background values. The ratio of heavy metals concentrations to background values, known as the pollution index, also differed notably across locations. For instance, Pb (mean 108.6 : background value 23.5) in Guangzhou, Cd (6.90 : 0.079) in Changsha, Zn (599.92 : 68) in Shenyang, as well as Cr (194.7 : 57.3), Ni (910.3 : 101.7) and Cu (1226.3 : 209.1) in Jinchang showed the highest pollution indices, indicating high additions to soil. The higher SDs of some metals reflect differences in the concentrations of heavy metals among study sites.[55] Additionally, CU experienced the highest asymmetric distribution with a greater degree of peakedness (kkewness=3.86 and kurtosis=15.1). Generally, heavy metals are natural elements of soil and their natural concentrations are low.[56] However, enhanced concentrations are very harmful and a direct response to urbanization and industrialization.[5] Unless serious measures are taken, the problem will continue, as urbanization has been rapid in China, increasing from 18% in 1978 to 46.6% in 2009 and is predicted to reach 65% by 2030.[57]

Soil heavy metals at the national level
The soil environment has degraded in China due to the continued increase in heavy metals which are toxic to the ecosystem. It is very difficult to recover soil health if soil is polluted with heavy metals.[58,59] The concentration level of heavy metals and their

spatial disparities across provinces can be seen in Table 2. Soil metals were greater than their reference levels in most of the provinces. This is especially evident for Cd, Zn and Cr in all provinces. This pollution often goes unnoticed by the public as metal contamination is colorless and odorless.[59] The concentrations of As and Ni, however, are lower in some provinces (*Table 2*).[60] Despite spatial variation, mean values indicate the severity of soil metals concentrations and the need for countermeasures. The highest variability in the mean values was observed for Zn (SD=20.01). The peak concentrations of most heavy metals (As, Zn, Ni, Cu and Hg) were found in Guizhou province, indicating that they share the same pollution source. Cadmium concentration distribution showed the highest skew value (skewness=3.25) and highest peakedness (kurtosis=11.47). Despite the increased levels of soil metals, the problem has not received much attention from policy makers in China.[54] The large number of sites (>1.5 million) and large volume of heavy metals discharges indicates that the trend of increased concentration levels and public and environmental health risk is continuing.[54]

Pollution level of soil heavy metals

For the analysis of soil heavy metals, I_{geo} and NIPI results are summarized in Table 3. Since its implementation in 1969 to quantify the metal concentration of sediments, I_{geo} has been widely used to identify the pollution level of soil heavy metals.[49] To evaluate soil environmental quality, different studies commonly use NIPI, as discussed below.[61–63]

Agricultural soil
Geo-accumulation index values ranged from -1.92 (Cr) to 4.44 (Cd). The mean I_{geo} of As, Pb, Cr, Ni and

	Place	As	Pb	Cd	Zn	Cr	Ni	Cu	Hg	Reference
In agricultural soil	Beijing	-	18.48	0.18	81.10	75.74	-	28.05	-	16
	Guangzhou	10.9	58.00	0.28	162.60	64.65	-	24.00	0.73	17
	Yangzhou	10.2	35.70	0.30	98.10	77.20	38.50	33.90	0.20	18
	Wuxi	14.3	46.7	0.14	112.9	58.6	-	40.4	0.16	19
	Gansu	11.2	21.44	-	-	38.82	-	27.20	0.15	22
	Chengdu	11.3	77.27	0.36	227.00	59.50	-	42.52	0.31	21
	Taihang	6.16	18.80	0.15	69.96	57.77	25.04	21.22	0.08	22
	Zhengzhou	6.69	17.11	0.12	-	60.67	-	-	0.08	23
	Kunshan	-	30.48	0.20	105.93	87.73	31.08	34.27	0.20	24
	Xuzhou	-	56.20	2.57	149.68	-	-	35.28	-	25
	Jinghe	14.9	22.44	0.14	-	44.21	-	-	-	26
	Hainan	8.06	48.01	0.28	52.17	22.67	15.51	30.25	-	27
Mean		**10.4**	**37.55**	**0.43**	**117.72**	**58.87**	**27.53**	**31.71**	**0.24**	
SD		**3.05**	**19.57**	**0.71**	**54.13**	**18.49**	**9.72**	**6.85**	**0.21**	
Skewness		**0.05**	**0.72**	**3.24**	**0.99**	**-0.45**	**-0.28**	**0.1**	**2.2**	
Kurtosis		**-0.9**	**-0.43**	**10.64**	**0.84**	**0.25**	**-0.24**	**-0.78**	**5.27**	
In urban soil	Beijing	-	28.60	0.15	65.60	35.60	27.80	23.70	-	28
	Guangzhou	-	108.6	0.50	169.24	-	25.67	62.57	-	29
	Shanghai	-	70.69	0.52	301.40	107.90	31.14	59.25	-	30
	Qingdao	-	62	0.3	201	54	17.3	55.0	-	31
	Jinchang	-	40.3	-	118.0	194.7	910.3	1226.3	1.11	32
	Hangzhou	-	75.7	1.30	148	47.5	24.1	41.0	-	33
	Changsha	-	89.40	6.90	276.00	121.00	-	51.40	-	34
	Hongkong	-	94.60	0.62	125.00	23.10	12.40	23.30	-	35
	Luoyang	-	65.92	1.71	215.75	71.42	-	85.40	-	36
	Nanjing	-	107.3	-	162.60	84.70	-	66.10	-	37
	Changchun	-	54.81	2.92	109.69	-	73.50	41.85	-	38
	Taicang	-	17.98	0.11	92.01	63.61	29.95	32.37	-	39
	Fuyang	-	40.59	0.37	159.85	-	21.92	40.77	-	40
	Shenyang	-	470.2	8.59	599.92	-	-	209.06	-	41
	Xuzhou	-	43.3	0.54	144.1	78.4	34.3	38.2	-	42
	Fuzhou	-	44.85	0.74	101.19	26.13	12.25	23.54	-	43
Mean		**-**	**88.43**	**1.81**	**186.83**	**75.67**	**101.7**	**129.9**	**-**	
SD		**-**	**105.3**	**2.64**	**127.34**	**48.24**	**255.1**	**295.7**	**-**	
Skewness		**-**	**3.56**	**2.04**	**2.52**	**1.41**	**3.44**	**3.86**	**-**	
Kurtosis		**-**	**13.5**	**3.24**	**7.58**	**2.46**	**11.8**	**15.1**	**-**	
Background value in all soil, China		9.6	23.5	0.079	68	57.3	26.9	20.7	0.038	58

Table 1 — Concentration of Soil Heavy Metals in Agricultural and Urban Soils across Sample Sites (mg.kg)

Abbreviations: SD, standard deviation; As, arsenic; Pb, lead; Cd, cadmium; Zn, zinc; Cr, chromium; Ni, nickel; Cu, copper; Hg. mercury.

Cu revealed that agricultural soil was not contaminated by these metals. Cadmium (0.93) and Zn (0.07) were present in soil at light to moderate level contamination levels, whereas Hg (1.7) was moderately contaminated in soil. Heavy metals contamination levels varied across provinces. For example, agricultural soil in Xuzhou was strongly to extremely seriously polluted with Cd (I_{geo}=4.44) and strongly polluted in Yangzhou with Hg (I_{geo}=3.68). Based on standard

deviation, Cd (1.23) and Hg (1.04) showed relatively high variability in their soil pollution levels. Even though the pollution level based on the mean I_{geo} values was promising, total pollution status using NIPI is more troubling. This provides clearer insight into soil environmental quality as this index takes into account both the mean and maximum concentration of heavy metals.[64] The overall pollution level indicates that agricultural soil is heavily polluted in Xuzhou, Guangzhou,

Province and Sample Size	As	Pb	Cd	Zn	Cr	Ni	Cu	Hg
Anhui (n=1501)	10	26.7	0.161	65.4	69.1	28.2	26.4	0.059
Beijing (n = 175)	11.7	30.7	0.169	81	59.3	25.6	29.9	0.422
Chongqing (n = 758)	8.7	28.2	0.269	90.7	76.7	34.8	24.5	0.081
Fujian (n = 881)	7.1	51.2	0.125	75.4	36.5	14	18.5	0.132
Gansu (n = 2904)	12.2	24.5	0.146	71.8	68.2	33.1	25.2	0.04
Guangdong (n = 1424)	16.7	60.4	0.336	87.4	60.4	18.7	24.1	0.199
Guangxi (n = 1259)	23.7	42.4	1.046	110.5	112.9	37.7	29.3	0.225
Guizhou (n = 386)	31.1	38.6	0.752	138.9	89.9	59.9	40.2	0.238
Hainan (n = 167)	6.5	49.2	0.085	69.2	68.1	33.3	20.9	0.054
Hebei (n = 2653)	9.2	22	0.159	68.7	61.4	26.2	23	0.054
Heilongjiang (n = 1509)	8.5	21.6	0.109	65.3	60.8	25.7	21.1	0.05
Henan (n = 1801)	10.7	26.8	0.18	63.7	74.3	28.3	21.8	0.046
Hubei (n = 1470)	13	29.3	0.313	72.4	70.6	36.5	29.4	0.083
Hunan (n = 1945)	15.9	40.5	0.299	102.9	62.5	29.9	28.8	0.14
I. Mongolia (n = 1643)	7.7	21.6	0.086	55.4	45.7	20.3	15.2	0.031
Jiangsu (n = 801)	9.7	33.1	0.177	78	80.1	33.2	27.7	0.133
Jiangxi (n = 1801)	20.9	38	0.187	93.3	65.4	26.6	32.1	0.109
Jilin (n = 1737)	10.8	24.1	0.12	54.5	41.5	19.5	16.7	0.044
Liaoning (n = 1552)	5.7	24	0.18	67.7	65.3	25.8	32.9	0.091
Ningxia (n = 386)	11.6	19	0.136	58.6	66	28	22.9	0.025
Qinghai (n = 636)	14.5	22.5	0.172	66.9	62.4	27.6	21.7	0.03
Shaanxi (n = 870)	12.2	29.2	0.266	81.8	79	34.9	29.6	0.1
Shandong (n = 2044)	9.1	24.2	0.121	73.1	60.4	28.8	24.8	0.037
Shanghai (n = 162)	9	26.4	0.214	97.5	72.4	35.6	27.1	0.131
Shanxi (n = 1500)	9.5	19.6	0.154	64.2	63.5	26.7	23.4	0.045
Sichuan (n = 2678)	10.2	32.6	0.335	94.5	93.1	38.3	34.6	0.086
Tianjin (n = 171)	9.5	26.6	0.188	104.8	67.9	31.5	28.4	0.081
Tibet (n = 373)	21.4	38.2	0.171	79.2	97.9	48	24.4	0.063
Xinjiang (n = 690)	11.9	27	0.169	69	54.2	27.9	26.4	0.02
Yunnan (n = 1505)	19.2	57.6	0.179	123.1	106.5	47.5	60.3	0.152
Zhejiang (n = 1152)	9	40	0.211	95.9	51.1	20.6	26.2	0.139
Background value in soil, China [58]	9.6	23.5	0.079	68	57.3	26.9	20.7	0.038
Mean	12.48	32.12	0.23	81.32	69.13	30.73	27.02	0.1
SD	5.65	11.01	0.19	20.01	17.25	9.27	8.07	0.08
Skewness	1.67	1.14	3.25	1.08	0.72	1.13	2.42	2.21
Kurtosis	2.92	0.62	11.47	1.04	0.84	2.4	9.18	6.54

Table 2 — *Concentration of Soil Heavy Metals Based on Mean Values (10th Percentile-90th Percentile) Across Provinces in China (mg/kg)*

Abbreviations: SD, standard deviation; As, arsenic; Pb, lead; Cd, cadmium; Zn, zinc; Cr, chromium; Ni, nickel; Cu, copper; Hg, mercury.

Urban soil

The geo-accumulation index (I_{geo}) of heavy metals in urban soil is generally higher than in agricultural soils (*Table 3*), indicating that urban soil is relatively more polluted and that the major risk factor is human activity. Spatial disparities in the pollution level of metals were also found to be higher in urban soils than agricultural soils, indicating dissimilar anthropogenic influences and levels of industrialization. Mean I_{geo} values ranged from moderate to strong pollution levels in the case of Cd (2.41) to no pollution for Cr (-0.41). In addition, Cd showed higher I_{geo} values, followed by Pb. The urban soil of most cities was heavily polluted with higher NIPI values (≥3) (*Table 3*). This increasing agricultural to urban gradient of heavy metals soil pollution revealed the corresponding intensity of urbanization and industrialization which enhances environmental damage. This indicates that urban soil quality is deteriorating, with adverse effects on the health of urban green plants, decreased water quality and increased risks to human health.[29]

Pollution level of soil heavy metals at the national scale

Heavy metals soil pollution was found in every province. The average I_{geo} value for soil contamination showed slight to moderate pollution for Cd. Only Cd in Guangdon and Sichuan and Hg in Beijing and Gansu showed moderate pollution levels. The overall soil contamination level was evaluated using NIPI, revealing that Beijing, Hubei, Hunan, Guangdong, Guangxi, Sichuan, Guizhou and Yunnan provinces had heavily polluted soils. Inner Mongolia was the only province with a good soil pollution status (0.7 < NIPI ≤1, precaution domain). The rest were in the category of slight to moderate pollution (*Table 4*). It is possible that soil metals pollution has recently increased in China. This is

Chengdu, Kunshan, Yangzhou, Wuxi and Gansu provinces (NIPI ≥3). This agricultural soil pollution leads to further pollution of agricultural products. For instance, in Shaoguan, the pollution level of rice is far greater than the maximum permissible limit (0.2 mg/kg) for the average concentration of Cd (0.69 mg/ kg) and Pb (0.39 mg/kg), elevating the risk of these metals entering the human body.[54,65]

evidenced by the fact that the pollution levels in urban and agricultural soil in Beijing were not found to be elevated in earlier studies as shown in Table 2, while a recent study at the national level found that soil is heavily polluted (*Table 4*). Further enrichment of soil heavy metals in China needs to be remediated by enacting effective measures relying on recent research results.[52]

Sources of soil heavy metals

Natural sources

The increase in heavy metals soil pollution is partly attributed to natural factors such as volcanic eruptions and continental dusts, as well as soil's parent materials and pedogenetic processes.[56,66] One of the major reasons for variations in the natural concentration levels of heavy metals in China across different soil types is differences in soil-forming rocks and minerals.[67–70] The concentrations of several heavy metals were positively correlated with concentrations of iron or aluminium oxides in soils, reflecting the influence of pedogenesis on these elements.[67,71] In addition, the acidic nature of soils is one of the reasons for high accumulations of heavy metals in the tropical and subtropical regions of southern China.[72] Each soil type has a different capacity to restore soil resilience.[73] However, the natural level of metals in soil is generally low and does not pose a threat.[56]

Anthropogenic sources

Rapid industrialization and urbanization over the last three decades are the main sources of enhanced heavy metals in the environment.[74,75] The dominant sources include sewage irrigation, mining, sludge application and smelting operations for metallic ores, industrial wastes and combustion of fossil fuels.[52,76] Coal consumption in 2010 emitted approximately 9000, 360,

	Place	I_{geo}								NIPI
		As	Pb	Cd	Zn	Cr	Ni	Cu	Hg	
In agricultural soil	Beijing	-	-0.93	0.6	-0.33	-0.18	-	-0.15	-	1.89
	Guangzhou	-0.4	0.72	1.24	0.67	-0.41	-	-0.37	3.68	13.95
	Yangzhou	-0.5	0.02	1.34	-0.06	-0.15	-0.07	0.13	1.81	3.98
	Wuxi	-0.01	0.41	0.24	0.15	-0.55	-	0.38	1.49	3.33
	Gansu	-0.37	-0.72	-	-	-1.15	-	-0.19	1.4	3.04
	Chengdu	-0.35	1.13	1.6	1.15	-0.53	-	0.45	2.44	6.26
	Taihang	-1.23	-0.91	0.34	-0.54	-0.57	-0.69	-0.55	0.49	1.72
	Zhengzhou	-1.11	-1.04	0.02	-	-0.5	-	-	0.49	1.74
	Kunshan	-	-0.21	0.76	0.05	0.03	-0.38	0.14	1.81	4.02
	Xuzhou	-	0.67	4.44	0.55		-	0.18	-	24.01
	Jinghe	0.05	-0.65	0.24	-	-0.96	-	-	-	1.89
	Hainan	-0.84	0.45	1.24	-0.97	-1.92	-1.38	-0.04		2.7
Mean		**-0.53**	**-0.24**	**0.93**	**0.07**	**-0.63**	**-0.63**	**0**	**1.7**	**5.71**
SD		**0.45**	**0.76**	**1.23**	**0.65**	**0.55**	**0.56**	**0.32**	**1.04**	**6.69**
In urban soil	Beijing	-	-0.3	0.34	-0.64	-1.27	-0.54	-0.39	-	1.57
	Guangzhou	-	1.62	2.08	0.73		-0.65	1.01	-	5.11
	Shanghai	-	1	2.13	1.56	0.33	-0.37	0.93	-	5.21
	Qingdao	-	0.81	1.34	0.98	-0.67	-1.22	0.82	-	3.13
	Jinchang	-	0.19	-	0.21	1.18	4.5	5.3	4.28	44.57
	Hangzhou	-	1.1	3.46	0.54	-0.86	-0.74	0.4	-	12.02
	Changsha	-	1.34	5.86	1.44	0.49	-	0.73	-	63.35
	Hongkong	-	1.42	2.39	0.29	-1.9	-1.7	-0.41	-	5.85
	Luoyang	-	0.9	3.85	1.08	-0.27	-	1.46	-	16
	Nanjing	-	1.61	-	0.67	-0.02	-	1.09	-	3.83
	Changchun	-	0.64	4.62	0.1	-	0.87	0.43	-	26.92
	Taicang	-	-0.97	-0.11	-0.15	-0.43	-0.43	0.06	-	1.4
	Fuyang	-	0.2	1.64	0.65	-	-0.88	0.39	-	3.69
	Shenyang	-	3.74	6.18	2.56	-	-	2.75	-	81.2
	Xuzhou	-	0.3	2.19	0.5	-0.13	-0.23	0.3	-	5.16
	Fozhou	-	0.35	2.64	-0.01	-1.72	-1.72	-0.4	-	6.85
Mean		**-**	**0.87**	**2.41**	**0.66**	**-0.41**	**-0.26**	**0.9**	**-**	**17.86**
SD		**-**	**1.01**	**1.8**	**0.74**	**0.87**	**1.58**	**1.37**	**-**	**23.47**

Table 3 — Geo-accumulation Index (I_{geo}) and Nemerow Integrated Pollution Index (NIPI) of Heavy Metals in Agricultural and Urban Soil
Abbreviations: SD, standard deviation; As, arsenic; Pb, lead; Cd, cadmium; Zn, zinc; Cr, chromium; Ni, nickel; Cu, copper; Hg, mercury.

450 and 25000 tons of As, Cd, Hg and Pb, respectively.[72] Nearly 80% of the total national electricity generation is from coal-fired power plants, which are the most important sources of metal input into soil.[77] Atmospheric deposition is another source of heavy metal contamination.[78] The rate of atmospheric deposition in China is higher than in other developed countries. Atmospheric deposition of Cd ranges from 0.4 to 25 g ha^{-1} year^{-1} with a mean of 4 g ha^{-1} yr^{-1} in China.[72]

This figure is substantially higher than the current mean for the European Union (0.35 g ha^{-1} yr^{-1}).[79] Farming practices using water irrigation, animal manure and chemical fertilizers are other contributing factors to increased Cd, Cu and Zn in agricultural soil.[6] The contribution of different human activities to the metals pollution rate in farmland soil in China is presented in Table 5.[52]

Lack of effective environmental

Province	I_{geo}								NIPI
	As	Pb	Cd	Zn	Cr	Ni	Cu	Hg	
Anhui	-0.64	-0.63	0.51	-0.73	-0.6	-0.93	-0.49	0.6	1.7
Beijing	-0.23	-0.31	0.58	-1.03	-0.79	-0.88	-0.33	1.55	8.06
Chongqing	-0.92	-0.23	0.37	0.16	-0.02	-0.1	-0.37	-0.2	2.66
Fujian	-1.07	-0.75	0.15	-0.94	-1.24	-1.74	-1.52	0.07	2.65
Gansu	-0.71	-0.36	-0.54	-0.57	-0.6	-0.78	-0.52	1.08	1.57
Guangdong	-0.22	-0.44	1.74	-0.1	-0.83	-0.98	-0.85	0.17	4.03
Guangxi	-1.27	-0.05	-0.26	-0.75	-0.6	-0.8	-1.01	-0.95	9.73
Guizhou	-1.12	-0.67	-2.15	-0.85	-1.37	-1.04	-0.99	-0.69	7.19
Hainan	-1.56	-0.47	-0.28	-0.54	-1.22	-1.06	-1.26	-0.89	1.71
Hebei	-1.31	-0.93	-0.04	-0.88	-0.93	-1.06	-0.73	-0.06	1.65
Heilongjiang	-1.13	-0.78	-0.28	-0.74	-0.61	-0.56	-0.63	-0.74	1.23
Henan	-0.81	-0.17	0.7	-0.55	-0.43	-0.71	-0.57	0.05	1.84
Hubei	-0.68	-0.54	0.18	-1.06	-0.95	-0.89	-0.89	-0.77	3.06
Hunan	-0.87	-0.33	0.23	-0.6	-0.86	-0.91	-0.6	-0.27	3.03
I. Mongolia	-0.5	-1.13	0.01	-0.62	0.01	-0.82	-0.31	-0.73	0.97
Jiangsu	-0.75	-0.44	-0.18	-0.34	-0.53	-0.52	-0.38	-2.61	2.74
Jiangxi	-0.8	-0.45	-0.31	-0.53	-0.31	-0.46	-0.3	-0.04	2.38
Jilin	-0.6	-0.84	-0.48	-0.78	-0.92	-0.94	-0.89	-0.61	1.28
Liaoning	-1.31	-0.48	0.16	-0.64	-0.64	-0.77	-0.08	0.58	1.95
Ningxia	-0.65	-0.71	-0.51	-0.64	-0.39	-1.06	-0.63	-0.46	1.43
Qinghai	-0.61	-0.62	-0.36	-0.8	-0.66	-0.85	-0.78	-0.22	1.76
Shaanxi	-0.63	-0.42	0.47	-0.3	-0.23	-0.53	-0.28	0.65	2.68
Shandong	-0.73	-0.78	-0.32	-0.68	-0.92	-0.72	-0.8	0.29	1.34
Shanghai	-0.65	-0.29	-0.18	-0.26	-0.42	-0.39	-0.5	0.82	2.72
Shanxi	-0.78	-0.57	-0.55	-0.81	-0.59	-0.97	-0.91	-0.16	1.6
Sichuan	-0.89	-0.08	1.17	0.22	0.23	-0.04	0.1	-0.13	3.28
Tianjin	-0.78	-0.13	0.32	-0.44	-0.99	-0.84	-0.83	0.23	1.98
Tibet	-0.68	-0.34	0.46	-0.58	-0.63	-0.8	-0.78	0.29	1.98
Xinjiang	-0.69	-0.13	0.01	-0.57	-0.54	-0.55	-0.75	-0.25	2.01
Yunnan	-1.61	-0.72	-1	-0.67	-0.32	-0.95	-0.74	-0.16	3.29
Zhejiang	-1.16	0	0.77	-0.36	-1.06	-1.42	-0.78	0.09	2.84
Mean	**-0.85**	**-0.48**	**0.01**	**-0.58**	**-0.64**	**-0.81**	**-0.66**	**-0.11**	**2.79**

Table 4 — Geo-accumulation Index (I_{geo}) and Nemerow Integrated Pollution Index (NIPI) of Heavy Metals Across Provinces in China (mg/kg)

Abbreviations: As, arsenic; Pb, lead; Cd, cadmium; Zn, zinc; Cr, chromium; Ni, nickel; Cu, copper; Hg, mercury.

Remedial Measures for Heavy metals soil pollution

A comparison of nationwide soil surveys across time shows that concentrations of some heavy metals have significantly increased over the last 25 years.[10] In addition, contaminated soil sites have been identified and some attempts at remediation have been made over the past 20 years. A comprehensive management project for remediation of contaminated land was launched in 2014 by the Ministry of Agriculture and the Ministry of Finance, and pilot studies were carried out in Changsha, Zhuzhou, and Xiangtan.[13] An action plan for controlling soil pollution was also approved by the Ministry of Environmental Protection on March 18, 2014. Liability and funding issues were defined in soil pollution policies as shown in Table 6.[82]

Various remedial strategies are discussed in the following subsections. These strategies are used to minimize heavy metal concentrations in soil or in the edible part of plants to minimize health risks.

Controlling sources of contamination
Locating and controlling large pollution emission sources such as mining, smelting and other metal consuming industries is the first step to combatting soil pollution with heavy metals. This requires more rigorous monitoring and enforcement of environmental protection laws.[10] In 2011, China's first heavy metal pollution control plan for a particular area, Xiangjiang river basin, was officially approved by the State Council.[54] In the same year, the "12th National 5-Year Plan for Comprehensive Prevention and Control of Heavy Metal Pollution" was approved.[83] The main goals of this plan are to establish a complete heavy metal pollution control and risk assessment

protection policies is another contributing factor for soil pollution. China has a relatively recent legal framework for environmental protection. Protections against soil pollution began in 1972 after the country's participation in Human-Environment interactions at the

Stockholm Conference.[80] Despite China's environmental protection efforts, the rate of soil pollution is not yet under control. Economic and technological development has very often compromised environmental standards.[81]

system for the environment and health, effective control of pollution by reducing discharges of major heavy metals (Hg, Cr, As, Cd, and Pb) in key regions (eastern and central China) by 15% between 2011 and 2015, taking 2007 as reference, ensuring that discharges of major heavy metals in non-key regions do not exceed 2007 levels, and significantly reducing pollution incidents.[54]

Reducing phytoavailability of heavy metals

An important focus of risk management for polluted soil is the phytoavailability of heavy metals.[10] The acidic content of soil can be modified to reach the target soil pH (around 6.5) by various materials, but these efforts differ in their capacity for soil acid neutralization, reaction rate and cost. For example, grain Cd and Pb accumulation were decreased by applications of biochar due to its effect on soil pH.[84,85] However, up to 40 t ha⁻¹ biochar is required to achieve these reductions, making this a high cost remediation method.[84,85] In addition to biochar, other materials such as sepiolite, sewage sludge, red mud and oilseed rape have an impact on heavy metal immobilization in soil.[86,87]

Selecting and rearing of grain cultivars with low risk of contamination

The uptake and distribution of heavy metals varies across and within crop species.[88] Identifying cultivars' genetic variation in heavy metal accumulation is essential for replacing high-accumulating with low-accumulating cultivars.[10] A number of rice cultivars have been shown to uptake Cd into their root cells and sequester it in the vacuoles.[89,90] There is a rather high initial cost for identifying and rearing such cultivars, with costs declining later when more breeding lines are generated.[88]

Sources	Cu	Pb	Zn	Cd	As	Ni	Cr	Hg
Non-ferrous metal mining and smelting activities discharge large amounts of wastewater, waste gas and solid waste	41.42	31.01	49.04	63.2	18.38	35.39	5.22	55.05
Non-metallic mining and smelting activities: coal exploration, realgar ore, rare earth mining and oil exploration	12.43	10.57	6.70	41.46	3.37	1.11	8.40	37.23
Industrial activities (industrial plants)	35.17	0	7.69	43.99	0.64	37.21	0	6.50
Irrigation	-	10.41	-	18.67	8.70	7.87	-	6.18
Urban development	12.99	1.24	-	26.99	-	-	0.35	17.44
Chemical fertilizer and insecticides	-	-	-	7.24		3.04	-	-

Table 5 — Averages of Heavy Metal Pollution Rates Across Six Anthropogenic Sources (%)

Abbreviations: As, arsenic; Pb, lead; Cd, cadmium; Zn, zinc; Cr, chromium; Ni, nickel; Cu, copper; Hg, mercury.

Policies	Issue year	Issuing agency	Details
Take specific pollution measures when industries are relocated	2004	Former State Environmental Protection Administration	Remediation and restoration of soil contamination to be carried out by polluters
Environmental cleaning and remediation measures of soil pollution in Shenyang Municipality	2007	Shenyang Environmental Protection Bureau, Shenyang Urban Planning Land and Resources Bureau	Land user bears the cost of remediation. If not known, the government is responsible
Improving remediation measures of industrial sites in Chongqing Municipality	2008	Chongqing Municipal People's Government	Polluters (individual or parties) are responsible for remediation costs of contaminated soil. New land user also must know that previous users are responsible. If no guilty party is identified, government will be responsible for clean-up of soil. Responsible polluters, centralized special funds, local financial subsidy, and societal capital are the source of funding for clean-up measures
Recommendations for strengthening soil contamination prevention and remediation	2008	Ministry of Environmental Protection	
Temporary Measures of Soil Environmental Management of Sites	2009	Ministry of Environmental Protection	
Notice on Ensuring Safe Environment of Land Redevelopment and Reutilization after Closing and Relocating Contaminating Factory	2011	Yancheng Municipal People's Government	
Circular on Ensuring Safe Environment of Redevelopment and Reutilization of Industrial Site	2012	Ministry of Environmental Protection, Ministry of Industry and Information Technology, Ministry of Land Resources, Ministry of Housing and Urban Rural Development	
The 12th Five-Year Main Points of the National Pollution Prevention and Control	2012	Ministry of Environmental Protection	Identify pollution liabilities, combine pollution liabilities insurance system with special funds
Notice of Issuing Recent Work Arrangement of Soil Environment Protection and Comprehensive Clean-up	2013	State Council	Principles of polluter-pays and investor-benefits should be respected while making investment. Key project will be supplied subsidy by the central government
Administrative Measures for the Special Funds for the Restoration and Management of the Geological Environment of Mines	2013	Ministry of Finance, Ministry of Land Resources	Special fund for polluted soil due to mining

Table 6 — Liability and Funding Issues in Soil Pollution Policies in China

Source: Li, Jiao, Xiao, Chen and Chang[82]

Paddy water and fertilizer management

One of the major sources of dietary As and Cd is paddy rice, and severity varies across different water management practices. Field experiments in seven major rice cultivars by Hu et al. indicated a significant increase of soil acid (hydrochloric acid) and extractable As concentrations, and a decrease in extractable Cd.[91] In addition, soil redox status heavily affects the bio-availability of some elements (Cr, Fe, As) and is directly influenced by the amount of soil moisture. This highlights the importance of water management in minimizing heavy metal contamination.[92] A study of Japanese rice grains suggested that the concentration trend of two important pollutants (As and Cd) was not managed using the water management method alone due to differences in the properties of the soils.[93] The application of silicone fertilizer has a positive effect in reducing As concentration in rice straw (78%) and rice grain (16%), but negatively affects soil by increasing its contamination.[94] The application of zinc fertilization with red mud, rape straw and corn straw minimized Cd pollution in both soil and vegetables.[95] Furthermore, application of organic matter in the form of Chinese vetch has been shown to fix pollutants in soil.[92] The combined use of organic and inorganic fertilizer in the subtropical region of China has minimized soil pollution by increasing microbial biomass carbon, nitrogen and phosphorus.[96]

Changing land use

If soil is heavily polluted, growing non-food crops and plants such as cotton, flax, broomcorn, grass, flowers and ornamental plants are the best remediation options.[10] For instance, covering the heavily degraded alpine meadow in Qinghai-Tibetan with *Elymus nutans* significantly improved total concentrations of phosphorus, neutral phosphatase, urease, and catalase as well as upgraded microbial biomass carbon, nitrogen and phosphorus in soil.[97] These non-food plants have economic value in addition to improving soil quality. Broom corn biomass could be used to make fiber and biogas, trees can be used for building materials, area greening, and seeds of castor oil plants can be used to make soap.[92]

Phytoremediation

Selected use of metal-accumulating plants for soil cleaning is an emerging technology which is low-cost and environmentally friendly.[10] There are four main functions of this technology: phytoextraction, the use of metal accumulating plants to remove toxic metals from soil; phytovolatilization, evaporation of certain metals from aerial parts of the plant; phytostabilitzation, the use of plants to eliminate the bioavailability of toxic metals in soils; and rhizofiltration, the use of plant roots to remove toxic metals from polluted waters.[97] For example, phytoextraction using non-irrigated rice cultivars grown for 2 years eliminated 883 g Cd ha^{-1}, decreased the total soil Cd content by 38%, and minimized the grain Cd content by 47% in subsequently grown Japonica food rice.[98] Selection of crop varieties with low heavy metal absorbability is very important for lowering heavy metals concentrations in the edible parts of plants to levels lower than food safety standards.[92]

Engineering techniques

This approach includes soil excavation, soil washing or burning to remediate metal contaminated soils. However, these techniques destroy the biotic components of soil and are technically difficult and implementation is economically unviable.[66]

Impact of soil heavy metals

China feeds 22% of the world's population, but has only 7% of the world's arable land, and is hampered by soil quality problems mainly owing to the rapid rate of industrial development and urbanization.[13,99] There is little doubt that soil contamination in China is becoming a threat to sustainable development.[9] Soil pollution due to accumulations of heavy metals over natural background levels has led to environmental quality deterioration.[92] About 10 million hectares of arable land has been polluted in China.[11] Hence, high concentrations of heavy metals occur not only in soil, but also in food crops, particularly in southern China.[10] A high proportion of rice grain exceeded the Cd limit in some areas of southern China, especially those areas impacted by mining and industrial activities.[100] Furthermore, a recent survey of rice in the Xiangjiang river basin, Hunan province, found that 60% of sampled grain contained 0.2 mg Cd kg^{-1}, while 11% contained more than 1.0 mg Cd kg^{-1}.[101] Another study in the Yangtze River region found that 37%, 16%, 60% and 70% of the sampled rice grain was contaminated with Cd, Hg, Pb and Cr, respectively.[102] Residents living in contaminated areas who consume mainly locally produced grain and vegetables are particularly vulnerable to health risks.[10] The entrance of heavy metals into humans through the food chain could lead to dangerous commutative health hazards. Due to the non-biodegradable nature of trace elements in the human digestion system, they have a long-term effect. High remediation costs have an adverse effect on China's economy. Heavy metal pollution has a great influence on ecological functions by harming the health of green plants and decreasing water quality.[29] Soil pollution has multidimensional impacts on the

economy (e.g. remediation costs), and on human health though the food chain, direct infiltration due to dermal contact, inhalation from air, as well as degrading ecological functions, threatening environmental sustainability.

Study limitations

The concentrations of heavy metals and the calculation of indices in this study were based on a review of the available literature from 2003 to 2015. Even though most of the reviewed papers were similar in terms of sample soil depth, there were disparities in the number of samples per unit area across the study locations. In addition, sample distribution was not spatially uniform and may not represent the comprehensive soil pollution situation in China. China is very large geographically, with diverse biophysical and socioeconomic settings. In addition, the magnitude of metal inputs into soil are changing over time due to rapid industrialization and urban development. Therefore, synthesis of the results from studies conducted at different times might underestimate pollution levels.

Conclusions

The present study reviewed over 100 individual studies to determine the concentration, pollution level, sources, remedial actions and impacts of soil heavy metals in China. Although the natural level of heavy metals in soil is low in China, enhanced heavy metals concentrations is an increasing problem associated with rapid industrialization and agricultural intensification. Most concentrations of heavy metals were higher than their background values. There were variations in concentration and pollution levels among heavy metals in different places, signifying uneven distribution of anthropogenic influences. Spatially, soil pollution was more prevalent in urban than agricultural soils. At the national level, soil pollution was more widespread in southern China than in the north and west. Based on the integrated pollution index, about 53% of the provinces were in the category of moderate and heavy pollution levels (NIPI>2). As a result of soil pollution, green plants and agricultural grain products are increasingly polluted, creating public and ecological health risks. This has also impacted China's economy, such as remediation costs. The major sources of heavy metals in soil were waste water and gases, hazardous solid wastes and agricultural inputs. Natural sources such as soil parent materials and volcanic eruptions have low contributions, unlike anthropogenic sources. Different remedial actions have been taken to minimize soil heavy metals and to limit their mobility into the food chain. However, effective control of pollution sources and remediation of polluted soils have not yet been realized and are complicated by rapid industrialization, urbanization and agricultural intensification.

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References

1. **Zhang M, Cui W, Yang H**. Effects of soil erosion on soil quality in rocky mountain areas of northern China [Internet]. 2011 International Conference on Remote Sensing, Environment and Transportation Engineering; 2011 Jun 24-26; Nanjing, China. Piscataway, NJ; Institute of Electrical and Electronics Engineers; 2011. p. 5936-9.

2. **Blanco-Canqui H, Lal R**. Erosion control and soil quality. In: Principles of soil conservation and management. Berlin: Springer; 2008. p. 477-92.

3. **Doran JW**. Soil health and global sustainability: translating science into practice. Agric Ecosyst Environ [Internet]. 2002 Feb [cited 2018 May 21];88(2):119-27. Available from: https://doi.org/10.1016/S0167-8809(01)00246-8 Subscription required to view.

4. **Chen X, Lu X**. Contamination characteristics and source apportionment of heavy metals in topsoil from an area in Xi'an city, China. Ecotoxicol Environ Saf [Internet]. 2018 Apr 30 [cited 2018 May 21];151:153-160. Available from: https://doi.org/10.1016/j.ecoenv.2018.01.010 Subscription required to view.

5. **He B, Yun Z, Shi J, Jiang G**. Research progress of heavy metal pollution in China: sources, analytical methods, status, and toxicity. Chinese Sci Bull [Internet]. 2013 Jan [cited 2018 May 21];58(2):134-40. Available from: https://link.springer.com/article/10.1007/s11434-012-5541-0

6. **Nicholson FA, Smith SR, Alloway BJ, Carlton-Smith C, Chambers BJ**. An inventory of heavy metals inputs to agricultural soils in England and Wales. Sci Total Environ [Internet]. 2003 Jul [cited 2018 May 21];311(1-3):205-19. Available from: https://doi.org/10.1016/S0048-9697(03)00139-6 Subscription required to view.

7. **Arshad MA, Martin S**. Identifying critical limits for soil quality indicators in agro-ecosystems. Agric Ecosyst Environ [Internet]. 2002 Feb [cited 2018 May 21];88(2):153-60. Available from: https://doi.org/10.1016/S0167-8809(01)00252-3 Subscription required to view.

8. **Qi YB, Huang B, Darilek JL**. Impacts of agricultural land management on soil quality after 24 years: a case study in Zhangjiagang County, China. N. Z. J Agric Res [Internet]. 2011 [cited 2018 May 21];54(4):261-73. Available from: https://doi.org/10.1080/00288233.2011.604678

9. **Jie C, Jing-zhang C, Man-zhi T, Zi-tong G**. Soil degradation: a global problem endangering sustainable development. J Geogr Sci [Internet]. 2002 Apr [cited 2018 May 21];12(2):243-52. Available from: http://dx.doi.org/10.1007/BF02837550 Subscription required to view.

10. **Zhao FJ, Ma Y, Zhu YG, Tang Z, McGrath SP**. Soil

contamination in China: current status and mitigation strategies. Environ Sci Technol [Internet]. 2015 Jan 20 [cited 2018 May 21];49(2):750-9. Available from: https://pubs.acs.org/doi/10.1021/es5047099 Subscription required to view.

11. Teng Y, Ni S, Wang J, Zuo R, Yang J. A geochemical survey of trace elements in agricultural and non-agricultural topsoil in Dexing area, China. J Geochem Explor [Internet]. 2010 Mar [cited 2018 May 21];104(3):118-27. Available from: https://doi.org/10.1016/j.gexplo.2010.01.006 Subscription required to view.

12. Cheng S. Heavy metal pollution in China: origin, pattern and control. Environ Sci Pollut Res Int [Internet]. 2003 [cited 2018 May 21];10(3):192-8. Available from: https://link.springer.com/article/10.1065/espr2002.11.141.1 Subscription required to view.

13. Teng Y, Wu J, Lu S, Wang Y, Jiao X, Song L. Soil and soil environmental quality monitoring in China: a review. Environ Int [Internet]. 2014 Aug [cited 2018 May 21];69:177-99. Available from: https://doi.org/10.1016/j.envint.2014.04.014 Subscription required to view.

14. Luo W, Wang T, Lu Y, Giesy JP, Shi Y, Zheng Y, Xing Y, Wu G. Landscape ecology of the Guanting Reservoir, Beijing, China: multivariate and geostatistical analyses of metals in soils. Environ Pollut [Internet]. 2007 Mar [cited 2018 May 21];146(2):567-76. Available from: https://doi.org/10.1016/j.envpol.2006.08.001 Subscription required to view.

15. Linde M. Trace metals in urban soils: Stockholm as a case study [doctorial thesis]. [Uppsala, Sweden]: Swedish University of Agricultural Sciences; 2005. 50 p.

16. Liu WH, Zhao JZ, Ouyang ZY, Soderlund L, Liu GH. Impacts of sewage irrigation on heavy metal distribution and contamination in Beijing, China. Environ Int [Internet]. 2005 Aug [cited 2018 May 21];31(6):805-12. Available from: https://doi.org/10.1016/j.envint.2005.05.042 Subscription required to view.

17. Li J, Lu Y, Yin W, Gan H, Zhang C, Deng X, Lian J. Distribution of heavy metals in agricultural soils near a petrochemical complex in Guangzhou, China. Environ Monit Assess [Internet]. 2009 Jun [cited 2018 May 21];153(1-4):365-75. Available from: https://link.springer.com/article/10.1007%2Fs10661-008-0363-x Subscription required to view.

18. Huang SS, Liao QL, Hua M, Wu XM, Bi KS, Yan CY, Chen B, Zhang XY. Survey of heavy metal pollution and assessment of agricultural soil in Yangzhong district, Jiangsu Province, China. Chemosphere [Internet]. 2007 May [cited 2018 May 21];67(11):2148-55. Available from: https://doi.org/10.1016/j.chemosphere.2006.12.043

Subscription required to view.

19. Zhao Y, Shi XZ, Huang B, Yu DS, Wang HJ, Sun WX, Oboern I, Blomback K. Spatial distribution of heavy metals in agricultural soils of an industry-based peri-urban area in Wuxi, China. Pedosphere [Internet].2007 Feb [cited 2018 May 21];17(1):44-51. Available from: https://doi.org/10.1016/S1002-0160(07)60006-X Subscription required to view.

20. Li Y, Gou X, Wang G, Zhang Q, Su Q, Xiao G. Heavy metal contamination and source in arid agricultural soil in central Gansu Province, China. J Environ Sci [Internet]. 2008 [cited 2018 May 21];20(5):607-12. Available from: https://doi.org/10.1016/S1001-0742(08)62101-4 Subscription required to view.

21. Liu C, Shang Y, Yin G. Primary study on heavy metals pollution in farm soil of Chengdu City. Guangdong Trace Elem Sci. 2006;13:41-5.

22. Yang P, Mao R, Shao H, Gao Y. The spatial variability of heavy metal distribution in the suburban farmland of Taihang Piedmont Plain, China. C R Biol [Internet]. 2009 Jun [cited 2018 May 21];332(6):558-66. Available from: https://doi.org/10.1016/j.crvi.2009.01.004 Subscription required to view.

23. Liu WX, Shen LF, Liu JW, Wang YW, Li SR. Uptake of toxic heavy metals by rice (Oryza sativa L.) cultivated in the agricultural soil near Zhengzhou city, People's Republic of China. Bull Environ Contam Toxicol [Internet]. 2007 Aug [cited 2018 May 21];79(2):209-13. Available from: https://link.springer.com/article/10.1007%2Fs00128-007-9164-0 Subscription required to view.

24. Chen F, Pu LJ. Relationship between heavy metals and basic properties of agricultural soils in Kunshan County. Soils. 2007;39:291-6.

25. Liu H, Han B, Hao D. Evaluation to heavy metals pollution in agricultural soils in northern suburb of Xuzhou City. Chin J Eco-Agric. 2006;14:159-61.

26. Zheng GZ. Investigation and assessment on heavy metal pollution of farming soil in the Jinghe River Basin. Arid Zone Res. 2008.

27. Zhao ZZ, Rate AW, Tang SX, Bi H. Characteristics of heavy metals distribution in agricultural soils of Hainan Island and its environment significances. J Agro-Environment Sci. 2008;27:182-7. Chinese

28. Zheng YM, Chen TB, He JZ. Multivariate geostatistical analysis of heavy metals in topsoils from Beijing, China. J Soils Sediment [Internet]. 2008 [cited 2018 May 21];8(1):51-8. Available from: https://link.springer.com/article/10.1065/jss2007.08.245 Subscription required to view.

29. Lu Y, Zhu F, Chen J, Gan H, Guo Y. Chemical fractionation of heavy metals in urban soils of Guangzhou, China. Environ Monit Assess [Internet].

2007 Nov [cited 2018 May 21];134(1-3):429-39. Available from: https://link.springer.com/article/10.1007/s10661-007-9634-1 Subscription required to view.

30. Shi G, Chen Z, Xu S, Zhang J, Wang L, Bi C, Teng J. Potentially toxic metal contamination of urban soils and roadside dust in Shanghai, China. Environ Pollut [Internet]. 2008 Nov [cited 2018 May 21];156(2):251-60. Available from: https://doi.org/10.1016/j.envpol.2008.02.027 Subscription required to view.

31. Yao D, Sun M, Yang FG, Jiang HY, Li GS, Ding CX. Environmental geochemistry of heavy metals in urban soils of Qingdao City. Geol China. 2008 Jun;35(3):539-50.

32. Liao X. Chen TB, Yan X, Xie H, Wu B, Nie CJ. Mining urban soil pollution: concentrations and patterns of heavy metals in the soils of Jinchang, China. Geogr Res. 2006 Jan;25(5):843-52.

33. Zhang MK, Zi-Xia KE. Heavy metals, phosphorus and some other elements in urban soils of Hangzhou city, China. Pedosphere. 2004;14(2):177-85.

34. Xi CZ, Dai TG, Haung DY. Investigation and assessment on pollution caused by soil heavy metals in Changsha city, Hunan province. Earth Environ. 2008 Jan;36:136-41.

35. Li X, Lee SL, Wong SC, Shi W, Thornton I. The study of metal contamination in urban soils of Hong Kong using a GIS-based approach. Environ Pollut [Internet]. 2004 May [cited 2018 May 21];129(1):113-24. Available from: https://doi.org/10.1016/j.envpol.2003.09.030 Subscription required to view.

36. Lu SG, Bai SQ, Xue QF. Magnetic properties as indicators of heavy metals pollution in urban topsoils: a case study from the city of Luoyang, China. Geophys J Int [Internet]. 2007 Nov [cited 2018 May 21];171(2):568-80. Available from: https://doi.org/10.1111/j.1365-246X.2007.03545.x

37. Lu Y, Gong Z, Zhang G, Burghardt W. Concentrations and chemical speciations of Cu, Zn, Pb and Cr of urban soils in Nanjing, China. Geoderma [Internet]. 2003 Jul [cited 2018 May 21];115(1-2):101-11. Available from: https://doi.org/10.1016/S0016-7061(03)00079-X Subscription required to view.

38. Ping G, Zhong-Lei X, Jun L, Chun-Li K, Jian-Hua. L Relationships between fractionations of Pb, Cd, Cu, Zn and Ni and soil properties in urban soils of Changchun, China. Chin Geogr Sci [Internet]. 2005 Jun [cited 2018 May 21];15(2):179-85. Available from: https://link.springer.com/article/10.1007%2Fs11769-005-0013-y Subscription required to view.

39. Zhong X, Zhou S, Zhao Q. Spatial characteristics and potential ecological risk of soil heavy metals contamination in the Yangtze River Delta: a case

study of Taicang City, Jiangsu Province. Sci Geogr Sin. 2007;27:395-400.

40. **Zhang XY, Lin FF, Wong MT, Feng XL, Wang K.** Identification of soil heavy metal sources from anthropogenic activities and pollution assessment of Fuyang County, China. Environ Monit Assess [Internet]. 2009 Jul [cited 2018 May 21];154(1-4):439-49. Available from: https://link.springer.com/article/10.1007%2Fs10661-008-0410-7 Subscription required to view.

41. **Li F, Fan Z, Xiao P, Oh K, Ma X, Hou W.** Contamination, chemical speciation and vertical distribution of heavy metals in soils of an old and large industrial zone in Northeast China. Environ Geol [Internet]. 2009 Jun [cited 2018 May 21];57(8):1815-23. Available from: https://link.springer.com/article/10.1007/s00254-008-1469-8 Subscription required to view.

42. **Wang XS, Qin Y.** Some characteristics of the distribution of heavy metals in urban topsoil of Xuzhou, China. Environ Geochem Health [Internet]. 2007 Feb [cited 2018 May 21];29(1):11-9. Available from: https://link.springer.com/article/10.1007%2Fs10653-006-9052-2 Subscription required to view.

43. **Zhenlan J, Yusheng Y, Jinming S.** Application of GWR model in hyperspectral prediction of soil heavy metal. ACTA Geogr Sin. 2017;72.

44. **Qingjie G, Jun D, Yunchuan X, Qingfei W, Liqiang Y.** Calculating pollution indices by heavy metals in ecological geochemistry assessment and a case study in parks of Beijing. J China Univ Geosci [Internet]. 2008 Jun [cited 2018 May 21];19(3):230-41. Available from: https://doi.org/10.1016/S1002-0705(08)60042-4 Subscription required to view.

45. **Lu X, Wang L, Lei K, Huang J, Zhai Y.** Contamination assessment of copper, lead, zinc, manganese and nickel in street dust of Baoji, NW China. J Hazard Mater [Internet]. 2009 Jan 30 [cited 2018 May 21];161(2-3):1058-62. Available from: https://doi.org/10.1016/j.jhazmat.2008.04.052 Subscription required to view.

46. **Lee CS, Li X, Shi W, Cheung SC, Thornton I.** Metal contamination in urban, suburban, and country park soils of Hong Kong: a study based on GIS and multivariate statistics. Sci Total Environ [Internet]. 2006 Mar 1 [cited 2018 May 21];356(1-3):45-61. Available from: https://doi.org/10.1016/j.scitotenv.2005.03.024 Subscription required to view.

47. **Jiang X, Lu WX, Zhao HQ, Yang QC, Yang ZP.** Potential ecological risk assessment and prediction of soil heavy-metal pollution around coal gangue dump. Nat Hazard Earth Syst Sci [Internet]. 2014 [cited 2018 May 21];14(6):1599-610. Available from: https://doi.org/10.5194/nhess-14-1599-2014

48. **Cheng H, Li M, Zhao C, Li K, Peng M, Qin A, Cheng X.** Overview of trace metals in the urban soil of 31 metropolises in China. J Geochem Explor [Internet]. 2014 [cited 2018 May 21];139:31-52. Available from: https://doi.org/10.1016/j.gexplo.2013.08.012

49. **Muller G.** Index of geoaccumulation in sediments of the Rhine River. GeoJournal. 1969;2:108-18.

50. **Obiora SC, Chukwu A, Davies T C.** Heavy metals and health risk assessment of arable soils and food crops around Pb–Zn mining localities in Enyigba, southeastern Nigeria. J Afr Earth Sci [Internet]. 2016 Apr [cited 2018 May 21];116:182-9. Available from: https://doi.org/10.1016/j.jafrearsci.2015.12.025 Subscription required to view.

51. **Buccolieri A, Buccolieri G, Cardellicchio N, Dell'Atti A, Di Leo A, Maci A.** Heavy metals in marine sediments of Taranto Gulf (Ionian Sea, Southern Italy). Mar Chem [Internet]. 2006 Mar [cited 2018 May 21];99(1-4):227-35. Available from: https://doi.org/10.1016/j.marchem.2005.09.009 Subscription required to view.

52. **Zhang X, Zhong T, Liu L, Ouyang X.** Impact of soil heavy metal pollution on food safety in China. PLoS One [Internet]. 2015 Aug 7 [cited 2018 May 21];10(8):e0135182. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4529268/

53. **Huang S, Tu J, Liu H, Hua M, Liao Q, Feng J, Weng Z, Huang G.** Multivariate analysis of trace element concentrations in atmospheric deposition in the Yangtze River Delta, East China. Atmos Environ [Internet]. 2009 Nov [cited 2018 May 21];43(36):5781-90. Available from: https://doi.org/10.1016/j.atmosenv.2009.07.055 Subscription required to view.

54. **Hu H, Jin Q, Kavan P.** A study of heavy metal pollution in China: current status, pollution-control policies and countermeasures. Sustain [Internet]. 2014 [cited 2018 May 21];6(9):5820-38. Available from: https://doi.org/10.3390/su6095820

55. **Qing X, Yutong Z, Shenggao L.** Assessment of heavy metal pollution and human health risk in urban soils of steel industrial city (Anshan), Liaoning, Northeast China. Ecotoxicol Environ Saf [Internet]. 2015 Oct [cited 2018 May 21];120:377-85. Available from: https://doi.org/10.1016/j.ecoenv.2015.06.019 Subscription required to view.

56. **Pan LB, Ma J, Wang XL, Hou H.** Heavy metals in soils from a typical county in Shanxi Province, China: levels, sources and spatial distribution. Chemosphere [Internet]. 2016 Apr [cited 2018 May 21];148:248-54. Available from: https://doi.org/10.1016/j.chemosphere.2015.12.049 Subscription required to view.

57. **Xu Q, Jiang Q, Cao K, Li X. Deng X.** Scenario-based analysis on the structural change of land uses in China. Adv Meteorol [Internet]. 2013 [cited 2018 May 21];2013:1-12. Available from: http://dx.doi.org/10.1155/2013/919013

58. **Wei F, Zheng C, Chen J, Wu Y.** Study of the background contents of 61 elements of soils in China. Huanjing Kexue. 1991;12(4):12-9.

59. **Su C, Jiang L, Zhang W.** A review on heavy metal contamination in the soil worldwide: situation, impact and remediation techniques. Environ Skept Crit [Internet]. 2014 [cited 2018 May 21];3(2):24-38. Available from: http://www.iaees.org/publications/journals/environsc/articles/2014-3%282%29/a-review-on-heavy-metal-contamination-in-the-soil-worldwide.pdf

60. **Chen H, Teng Y, Lu S, Wang Y, Wang J.** Contamination features and health risk of soil heavy metals in China. Sci Total Environ [Internet]. 2015 Apr 15 [cited 2018 May 21];512-513:143-153. Available from: https://doi.org/10.1016/j.scitotenv.2015.01.025 Subscription required to view.

61. **Cheng JL, Shi Z, Zhu YW.** Assessment and mapping of environmental quality in agricultural soils of Zhejiang Province, China. J Environ Sci (China) [Internet]. 2007 [cited 2018 May 21];19(1):50-4. Available from: https://doi.org/10.1016/S1001-0742(07)60008-4 Subscription required to view.

62. **Zang F, Wang S, Nan Z, Ma J, Zhang Q, Chen Y, Li Y.** Accumulation, spatio-temporal distribution, and risk assessment of heavy metals in the soil-corn system around a polymetallic mining area from the Loess Plateau, northwest China. Geoderma [Internet]. 2017 Nov 1 [cited 2018 May 21];305:188-96. Available from: https://doi.org/10.1016/j.geoderma.2017.06.008 Subscription required to view.

63. **Lu X, Zhang X, Li LY, Chen H.** Assessment of metals pollution and health risk in dust from nursery schools in Xi'an, China. Environ Res [Internet]. 2014 Jan [cited 2018 May 21];128:27-34. Available from: https://doi.org/10.1016/j.envres.2013.11.007 Subscription required to view.

64. **Han W, Gao G, Geng J, Li Y, Wang Y.** Ecological and health risks assessment and spatial distribution of residual heavy metals in the soil of an e-waste circular economy park in Tianjin, China. Chemosphere [Internet]. 2018 Apr [cited 2018 May 21];197:325-35. Available from: https://doi.org/10.1016/j.chemosphere.2018.01.043 Subscription required to view.

65. **Wang X, Zeng X, Chuanping L, Li F, Xu X, Lv Y.** Heavy metal contaminations in soil-rice system: source identification in relation to a sulfur-rich coal burning power plant in Northern Guangdong Province, China.

Environ Monit Assess [Internet]. 2016 Aug [cited 2018 May 21];188:460. Available from: https://doi.org/10.1007/s10661-016-5468-z Subscription required to view.

66.   **Hooda V. Phytoremediation of toxic metals from soil and waste water.** J Environ Biol [Internet]. 2007 Apr [cited 2018 May 21];28(2):367-76. Available from: https://pdfs.semanticscholar.org/5855/a3d15d4b470f598759dcf43a9a0821c66e61.pdf

67.   **Ander EL, Johnson CC, Cave MR, Palumbo-Roe B, Nathanail CP, Lark RM. Methodology for the determination of normal background concentrations of contaminants in English soil.** Sci Total Environ [Internet]. 2013 Jun 1 [cited 2018 May 21];454-455:604-18. Available from: https://doi.org/10.1016/j.scitotenv.2013.03.005

68.   **Reimann C, de Caritat P**. Distinguishing between natural and anthropogenic sources for elements in the environment: regional geochemical surveys versus enrichment factors. Sci Total Environ [Internet]. 2005 Jan 20 [cited 2018 May 21];337(1-3):91-107. Available from: https://doi.org/10.1016/j.scitotenv.2004.06.011 Subscription required to view.

69.   **Reimann C, Garrett RG**. Geochemical background—concept and reality. Sci Total Environ [Internet]. 2005 Nov 1 [cited 2018 May 21];350(1-3):12-27. Available from: https://doi.org/10.1016/j.scitotenv.2005.01.047 Subscription required to view.

70.   **Zhao FJ, McGrath SP, Merrington G. Estimates of ambient background concentrations of trace metals in soils for risk assessment.** Environ Pollut [Internet]. 2007 Jul [cited 2018 May 21];148(1):221-9. Available from: https://doi.org/10.1016/j.envpol.2006.10.041 Subscription required to view.

71.   **Hamon, RE, McLaughlin MJ, Gilkes RJ, Rate AW, Zarcinas B, Robertson A, Cozens G, Radford N, Bettenay L. Geochemical indices allow estimation of heavy metal background concentrations in soils.** Glob Biogeochem Cycles [Internet]. 2004 Mar [cited 2018 May 21];18(1):1-6. Available from: https://doi.org/10.1029/2003GB002063

72.   **Luo, L, Ma Y, Zhang S, Wei D, Zhu YG**. An inventory of trace element inputs to agricultural soils in China. J Environ Manage [Internet]. 2009 Jun [cited 2018 May 21];90(8):2524-30. Available from: https://doi.org/10.1016/j.jenvman.2009.01.011 Subscription required to view.

73.   **Lal R. Soil degradation by erosion.** Land Degrad Dev [Internet]. 2001 Nov/Dec [cited 2018 May 21];12(6):519-39. Available from: https://doi.org/10.1002/ldr.472 Subscription required to view.

74.   **Liaghati T, Preda M, Cox M.** Heavy metal distribution and controlling factors within coastal plain sediments, Bells Creek catchment, southeast Queensland, Australia. Environ Int [Internet]. 2004 Jan [cited 2018 May 21];29(7):935-48. Available from: https://doi.org/10.1016/S0160-4120(03)00060-6 Subscription required to view.

75.   **Zhao FJ, Ma Y, Zhu YG, Tang Z, McGrath SP. Soil contamination in China: current status and mitigation strategies.** Environ Sci Technol [Internet]. 2015 Jan 20 [cited 2018 May 21];49(2):750-9. Available from: https://pubs.acs.org/doi/10.1021/es5047099 Subscription required to view.

76.   **Fu SS, Li PJ, Feng Q, Li XJ, Sun YB, Chen Y. Soil quality degradation in a magnesite mining area.** Pedosphere [Internet]. 2011 Feb [cited 2018 May 21]; 21(1):98-106. Available from: https://doi.org/10.1016/S1002-0160(10)60084-7 Subscription required to view.

77.   **Wang Z Pan L, Li Y, Zhang D, Ma J, Sun F, Xu W, Wang X**. Assessment of air quality benefits from the national pollution control policy of thermal power plants in China: a numerical simulation. Atmos Environ [Internet]. 2015 Apr [cited 2018 May 21];106:288-304. Available from: https://doi.org/10.1016/j.atmosenv.2015.01.022 Subscription required to view.

78.   **Guo JH, Liu XJ, Zhang Y, Shen JL, Han WX, Zhang WF, Christie P, Goulding KW, Vitousek PM, Zhang FS**. Significant acidification in major Chinese croplands. Sci [Internet]. 2010 Feb 19 [cited 2018 May 21];327(5968):1008-10. Available from: http://science.sciencemag.org/content/327/5968/1008 Subscription required to view.

79.   **Six L, Smolders E**. Future trends in soil cadmium concentration under current cadmium fluxes to European agricultural soils. Sci Total Environ [Internet]. 2014 Jul 1 [cited 2018 May 21];485-486:319-328. Available from: https://doi.org/10.1016/j.scitotenv.2014.03.109 Subscription required to view.

80.   **Beyer S**. Environmental law and policy in the People's Republic of China. Chin J Int Law [Internet]. 2006 Feb 17 [cited 2018 May 21];5(1):185-211. Available from: https://doi.org/10.1093/chinesejil/jmk002 Subscription required to view.

81.   **Zhang KM, Wen Zg**. Review and challenges of policies of environmental protection and sustainable development in China. J Environ Manage [Internet]. 2008 Sep [cited 2018 May 21];88(4):1249-61. Available from: https://doi.org/10.1016/j.jenvman.2007.06.019 Subscription required to view.

82.   **Li XN, Jiao WT, Xiao RB, Chen WP, Chang AC. Soil pollution and site remediation policies in China: a review.** Environ Rev [Internet]. 2015 Mar [cited 2018 May 21];23(3):263-74. Available from: https://doi.org/10.1139/er-2014-0073 Subscription required to view.

83.   **Tang W, Zhao Y, Wang C, Shan B, Cui J.** Heavy metal contamination of overlying waters and bed sediments of Haihe Basin in China. Ecotoxicol Environ Saf [Internet]. 2013 Dec [cited 2018 May 21];98:317-23. Available from: https://doi.org/10.1016/j.ecoenv.2013.09.038 Subscription required to view.

84.   **Bian R, Chen D, Liu X, Cui L, Li L, Pan G, Xie D, Zheng J, Zhang X, Zheng J, Chang A**. Biochar soil amendment as a solution to prevent Cd-tainted rice from China: results from a cross-site field experiment. Ecol Eng [Internet]. 2013 Sep [cited 2018 May 21];58:378-83. Available from: https://doi.org/10.1016/j.ecoleng.2013.07.031 Subscription required to view.

85.   **Bian R, Joseph S, Cui L, Pan G, Li L, Liu X, Zhang A, Rutlidge H, Wong S, Chia C, Marjo C, Gong B, Munroe P, Donne S**. A three-year experiment confirms continuous immobilization of cadmium and lead in contaminated paddy field with biochar amendment. J Hazard Mater [Internet]. 2014 May 15 [cited 2018 May 21];272:121-8. Available from: https://doi.org/10.1016/j.jhazmat.2014.03.017 Subscription required to view.

86.   **Khan S, Reid BJ, Li G, Zhu YG**. Application of biochar to soil reduces cancer risk via rice consumption: a case study in Miaoqian village, Longyan, China. Environ Int [Internet]. 2014 Jul [cited 2018 May 21];68:154-61. Available from: https://doi.org/10.1016/j.envint.2014.03.017 Subscription required to view.

87.   **Zhu QH, Huang DY, Zhu GX, Ge TD, Liu GS, Zhu HH, Zhang XN**. Sepiolite is recommended for the remediation of Cd-contaminated paddy soil. Acta Agric Scand Sect. B–Soil Plant Sci [Internet]. 2010 [cited 2018 May 21];60(2):110-6. Available from: https://doi.org/10.1080/09064710802672624 Subscription required to view.

88.   **Grant CA, Clarke JM, Duguid S, Chaney RL.** Selection and breeding of plant cultivars to minimize cadmium accumulation. Sci Total Environ [Internet]. 2008 Feb 15 [cited 2018 May 21];390(2-3):301-10. Available from: https://doi.org/10.1016/j.scitotenv.2007.10.038 Subscription required to view.

89.   **Sasaki A, Yamaji N, Yokosho K, Ma JF. Nramp5 is a major transporter responsible for manganese and cadmium uptake in rice.** Plant Cell [Internet]. 2012 May [cited 2018 May 21];24(5):2155-67. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3442593/

90.   **Ueno D, Yamaji N, Kono I, Huang CF, Ando T, Yano M, Ma JF.** Gene limiting cadmium accumulation in rice. Proc Natl Acad Sci U S A [Internet]. 2010 Sep 21 [cited 2018 May 21];107(38):16500-5. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2944702/

Shifaw

91. **Hu P, Huang J, Ouyang Y, Wu L, Song J, Wang S, Li Z, Han C, Zhou L, Huang Y, Luo Y, Christie P.** Water management affects arsenic and cadmium accumulation in different rice cultivars. Environ Geochem Health [Internet]. 2013 Dec [cited 2018 May 21];35(6):767-78. Available from: https://doi.org/10.1007/s10653-013-9533-z Subscription required to view.

92. **Huamain C, Chunrong Z, Cong T, Yongguan Z.** Heavy metal pollution in soils in China: status and countermeasures. Ambio [Internet]. 1999 Mar [cited 2018 May 21];28(2):130-4. Available from: http://www.jstor.org/stable/4314863 Subscription required to view.

93. **Arao T, Kawasaki A, Baba K, Mori S, Matsumoto S.** Effects of water management on cadmium and arsenic accumulation and dimethylarsinic acid concentrations in Japanese rice. Environ Sci Technol [Internet]. 2009 Dec 15 [cited 2018 May 21];43(24):9361-7. Available from: https://pubs.acs.org/doi/abs/10.1021/es9022738 Subscription required to view.

94. **Li RY, Stroud JL, Ma JF, McGrath SP, Zhao FJ.** Mitigation of arsenic accumulation in rice with water management and silicon fertilization. Environ Sci Technol [Internet] 2009 [cited 2018 May 21];43(10):3778-83. Available from: https://pubs.acs.org/doi/abs/10.1021/es803643v Subscription required to view.

95. **Li B, Yang J, Wei D, Chen S, Li J, Ma Y.** Field evidence of cadmium phytoavailability decreased effectively by rape straw and/or red mud with zinc sulphate in a Cd-contaminated calcareous soil. PLoS One [Internet]. 2014 Oct 10 [cited 2018 May 21];9(10):e109967. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4193849/

96. **Odunze AC, Jinshui W, Shoulong L, Hanhua Z, Tida G, Yi W, Qiao L.** Soil quality changes and quality status: a case study of the subtropical China Region Ultisol. Br J Environ Clim Change [Internet]. 2012 Jan-Mar [cited 2018 May 21];2(1):35-57. Available from: http://www.sciencedomain.org/abstract/487

97. **Feng R, Long R, Shang Z, Ma Y, Dong S, Wang Y.** Establishment of Elymus natans improves soil quality of a heavily degraded alpine meadow in Qinghai-Tibetan Plateau, China. Plant Soil [Internet]. 2010 Feb [cited 2018 May 21];327(1-2):403-11. Available from: https://doi.org/10.1007/s11104-009-0065-3 Subscription required to view.

98. **Murakami M, Nakagawa F, Ae N, Ito M, Arao T.** Phytoextraction by rice capable of accumulating Cd at high levels: reduction of Cd content of rice grain. Environ Sci Technol [Internet]. 2009 [cited 2018 May 21];43(15):5878-83. Available from: https://pubs.acs.org/doi/abs/10.1021/es8036687 Subscription required

99. **Huili G, Dan M, Li X, Zhu F.** Soil degradation and food security coupled with global climate change in northeastern China. Chin Geogr Sci [Internet]. 2013 Oct [cited 2018 May 21];23(5):562-73. Available from: https://doi.org/10.1007/s11769-013-0626-5 Subscription required to view.

100. **Williams PN, Lei M, Sun G, Huang Q, Lu Y, Deacon C, Meharg AA, Zhu YG.** Occurrence and partitioning of cadmium, arsenic and lead in mine impacted paddy rice: Hunan, China. Environ Sci Technol [Internet]. 2009 Feb 1 [cited 2018 May 21];43(3):637-42. Available from: https://pubs.acs.org/doi/abs/10.1021/es802412r Subscription required to view.

101. **Du Y, Hu XF, Wu XH, Shu Y, Jiang Y, Yan XJ.** Affects of mining activities on Cd pollution to the paddy soils and rice grain in Hunan province, Central South China. Environ Monit Assess [Internet]. 2013 Dec [cited 2018 May 21];185(12):9843-56. Available from: https://doi.org/10.1007/s10661-013-3296-y Subscription required to view.

102. **Liu Z, Zhang Q, Han T, Ding Y, Sun J, Wang F, Zhu C.** Heavy metal pollution in a soil-rice system in the Yangtze River Region of China. Int J Environ Res Public Health [Internet]. 2016 Jan [cited 2018 May 21];13(1):63. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4730454/